[PROC. ROY. SOC. VICTORIA, **54** (N.S.), PT. II., 1942.]

ART IX.—*The Heavy Minerals of Some Victorian Granitic Rocks.*

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[Read 13th November, 1941; issued separately 31st August, 1942.]

Introduction.

The heavy mineral assemblages and index numbers (ratio of heavy to light minerals by weight) of granitic rocks have been examined in considerable detail in other parts of the world during the past few years, but little work of this nature has hitherto been carried out with Victorian granitic rocks (see 1, 3, 4, 6 and 68). Over 100 Victorian granitic rocks were therefore selected for heavy mineral examination. The greater number of these are granites, and the total treated represents almost one half of the localities where granitic rocks occur in Victoria. Previously it was stated that most of the acid plutonic rocks of Victoria were granodiorites (66, p. 295), but outcrops of granite are more common than was originally thought, although the total areal distribution of granodiorites may be the greater.

Most Victorian granitic rocks occur as stocks or batholiths. Their distribution is shown on the accompanying map, the extent and shapes of the exposures being modified from the sixteen miles to one inch geological map of Victoria (1909).

The specimens examined were obtained from surface outcrops, and little field data is available regarding the levels in the intrusions that such positions represent. Attempts have been made to correlate certain of the Victorian granitic masses and to differentiate others. Only partial success has been obtained in correlation, as more often there are greater differences than similarities between the various granitic rocks. The heavy mineral investigations indicate the occurrence, distribution and concentration of the heavy accessory minerals in greater detail than can be obtained by the examination of thin sections of rocks. In thin sections heavy accessories are seldom sufficiently concentrated to permit comprehensive observations, and many are often not seen or are passed over. It has been said for example, that sphene is generally absent from most Victorian granitic rocks (74, p. 33), but sphene has been found in the heavy mineral assemblages of over one third of the examples (see Table 5).

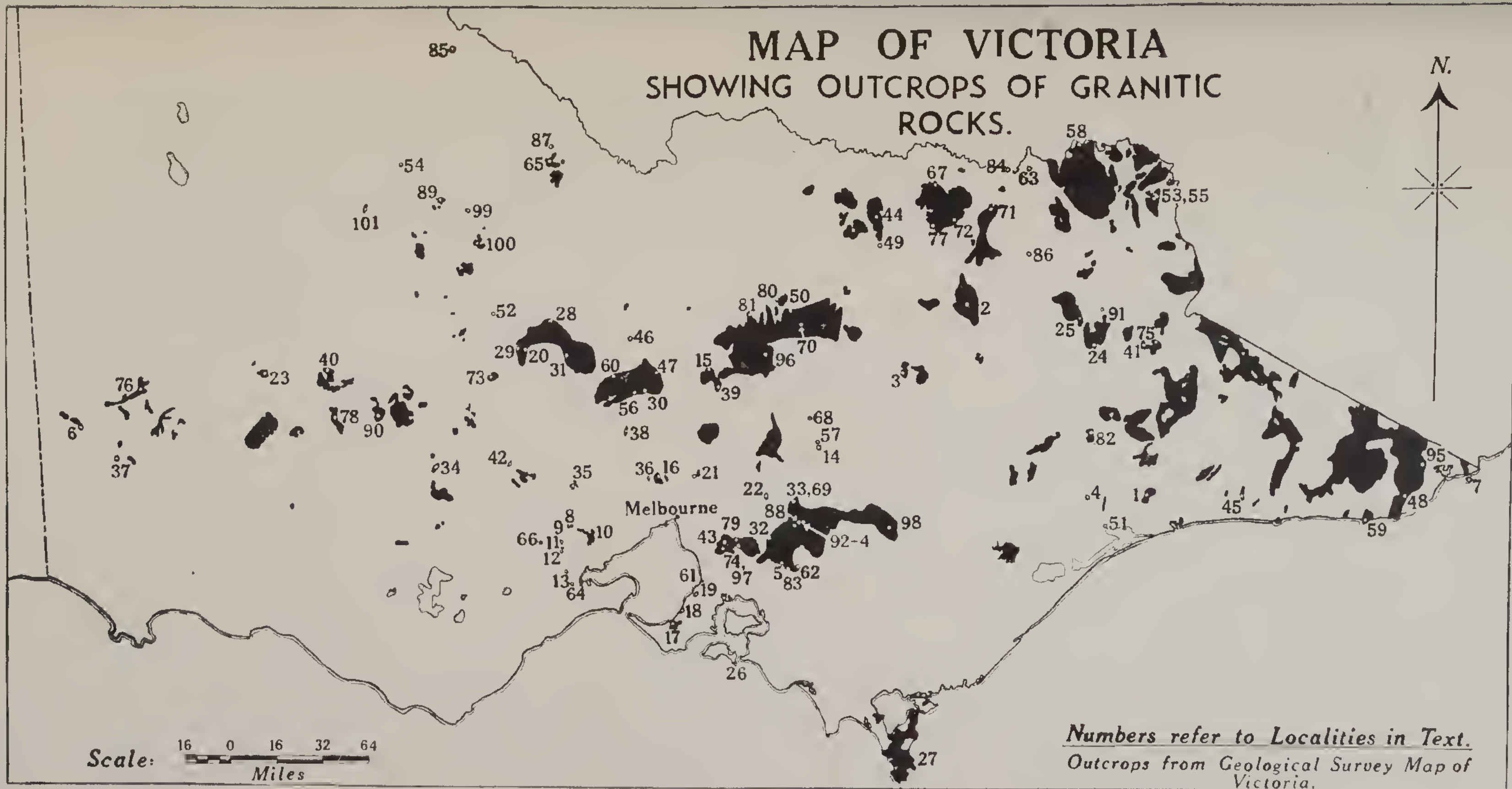
MAP OF VICTORIA
SHOWING OUTCROPS OF GRANITIC ROCKS.
N.
Melbourne
Scale:
16 0 16 32 64
Miles
Numbers refer to Localities in Text.
Outcrops from Geological Survey Map of Victoria.

FIG. 1.

Classification of the Granitic Rocks Examined.

The nomenclature of the granitic rocks is based mainly upon thin section investigations, accompanied in some instances by chemical and micrometric analyses carried out by previous workers. Specimens employed from hitherto undescribed outcrops have also been named from thin sections, aided in several instances by partial Rosiwal micrometric analyses (Table 1). The earlier nomenclature of a few examples has been modified in the light of more detailed examinations. Thus the Dromana stock, originally regarded as syenite (40) and later as granodiorite (49), proves to be a granite (3). The outcrop at Big Hill near Bendigo has been called granite (22), but the excess of plagioclase over orthoclase, and the high index number considered in conjunction with thin section examination, place it preferably with the granodiorites.

TABLE 1.

Locality.	*Ratio of orthoclase to plagioclase.*
1. Upper Beaconsfield	1.0 : 2.3
2. Zumstein's Crossing, Grampians	1.0 : 1.6
3. Narre Warren	1.0 : 1.6
4. Kerrisdale	1.0 : 1.5
5. Oliver's Hill, Frankston	1.0 : 1.4
6. Mt. Baw Baw	1.0 : 1.4
7. Big Hill, Bendigo	1.0 : 1.3
8. Gong Gong, Ballarat	1.0 : 1.3
9. Dromana	1.4 : 1.0
10. Terip Terip	1.8 : 1.0

The ratios of orthoclase to plagioclase for Nos. 2 to 8 in Table 1 are intermediate between the true granodiorites and the so-called adamellites according to Hatch's classification (36, p. 165), and the rocks should therefore be regarded as adamellites. Many other Victorian granitic rocks classed as granodiorites fall into a similar category, but as the term "adamellite" has been disallowed by the Petrological Nomenclature Committee, and as such rocks possess relatively high index numbers (see Table 5), it is preferred herein to classify them as granodiorites. In like manner, granitic rocks from Harcourt, Ingliston, Trawool (67) and Broadmeadows (65), previously classed as adamellites, should be classed with the granodiorites, unless as at Trawool (5), they prove to be contaminated granites. The original nomenclature of these four rocks is retained in this paper for present purposes, but the adopted scheme for the other granitic rocks is to regard those with excess of orthoclase as granites, and those with excess plagioclase as granodiorites.

The available micrometric and chemical analyses of Victorian granitic rocks, most of which have been examined for heavy minerals, are set out in the following tables (Tables 2 and 3) :—

TABLE 2.—TABLE OF MICROMETRIC ANALYSES OF SOME VICTORIAN GRANITIC ROCKS.

	Granites.				Granodiorites.							
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
Quartz	34·8	32·0	29·9	28·7	32·1	35·8	29·4	31·2	23·5	26·3	28·1	27·7
Orthoclase ..	33·9	34·7	34·1	34·8	15·1	21·7	17·6	16·3	17·4	6·6	12·4	23·3
Plagioclase ..	24·9	25·6	19·1	25·5	40·6	28·6	39·9	31·6	39·0	38·1	34·5	32·8
Biotite	4·3	5·7	6·5	8·8	7·2	11·4	12·2	18·6	15·5	27·3	24·0	12·1
Hornblende ..	1·5	..	..	1·3	5·2	0·1	0·6	..	4·6	..	..	2·5
Accessories ..	0·6	2·0	..	0·9	..	2·4	0·3	2·3	..	1·7	1·0	1·6
Cordierite ..	..	..	6·8	..	..	..	..	..	..	..	..	..
Muscovite ..	..	..	3·6	..	..	..	..	..	..	..	..	..

1.—Dromana (3). 2.—Powelltown (6). 3.—Terip Terip (5). 4.—You Yangs (1). 5.—Mt. Leinster (16). 6.—Oliver's Hill, Frankston (3). 7.—Mt. Eliza (59). 8.—Powelltown (6). 9.—Upper Beaconsfield. 10.—Braemar House, Macedon (25). 11.—Warburton (25). 12.—Mt. Baw Baw.

In Table 3 (and also in fig. 2), $a - r$ = granodiorites (including the so-called adamellites), and $s - y$ = granites.

a—Cavendish Heights, Toomuc Valley, Lysterfield Hills.
b—Braemar (Clyde) House, Macedon (60).
c—Scotchman's Creek, Warburton (25).
d—Omeo.
e—Bulla (69).
f—Yackandandah (68).
g—Broadmeadows (65).
h—Talbot Drive, Marysville (37).
i—Belgrave.
j—Quarry Hill, Morang (F. J. Watson, anal.).
k—Hesket (60).
l—Mt. Eliza, Mornington Peninsula (59).
m—Tintaldra (28).
n—Mt. Leinster (16).
p—Trawool (67).
q—Harcourt (67).
r—Ingliston (67).
s—Lake Boga (F. F. Field, anal.).
t—Gabo Island (67).
u—Mt. Buffalo (21).
v—Mt. Mittamatite (28).
w—Dog Rocks, Geelong (67).
y—Cape Woolamai (67).

From chemical analyses, Tattam classifies the Yackandandah rock (Table 3, column "f") as granite (68, p. 26); the sample from this district used in the heavy mineral analysis is classified as granodiorite because of the high index number, the high specific gravity, and the mineralogical composition. Both granite and granodiorite are recorded within a short distance of one another at Yackandandah (40, p. 221). The Tintaldra rock (Table 3, column "m") is classed with the granodiorites on heavy mineral evidence, although it has been stated from chemical analysis that it is as distinct from the granodiorites proper as from the granites proper (28).

Table 3.—Chemical Compositions of Some Victorian Granitic Rocks.

	a.	*b.*	*c.*	*d.*	*e.*	*f.*	*g.*	*h.*	*i.*	*j.*	*k.*	*l.*	*m.*	*n.*	*p.*	*q.*	*r.*	*s.*	*t.*	*u.*	*v.*	*w.*	*y.*
SiO_2 ..	63·61	64·04	64·87	65·59	66·13	67·25	67·75	67·07	67·27	69·17	68·92	69·46	67·67	67·71	69·19	70·94	71·57	70·94	72·48	73·30	74·29	75·99	76·31
Al_2O_3 ..	15·09	15·83	16·24	17·46	16·83	16·46	16·11	15·55	14·96	15·95	15·26	15·33	14·50	13·10	13·45	13·99	13·58	16·14	13·48	13·84	12·90	13·10	13·09
Fe_2O_3 ..	0·93	0·80	1·03	4·21	1·11	0·42	0·50	0·50	1·10	0·88	0·80	0·67	0·87	2·12	2·71	0·35	1·18	0·21	1·16	0·82	1·16	0·57	0·41
FeO ..	4·56	4·47	4·80	0·10	4·17	1·99	4·00	3·38	3·13	3·64	3·30	1·80	3·78	0·29	2·78	3·02	2·19	1·30	2·09	1·22	1·04	0·61	1·07
MgO ..	2·82	2·64	2·62	2·35	1·83	1·00	0·79	1·69	2·22	1·12	1·64	2·07	2·21	0·16	1·06	0·80	1·07	0·45	0·49	0·82	tr.	0·18	0·36
CaO ..	4·52	3·52	3·20	1·03	3·26	2·74	2·68	2·97	3·63	3·04	3·04	3·14	2·18	0·53	2·04	2·35	1·72	0·93	1·31	0·84	1·12	0·41	0·65
Na_2O ..	4·06	2·42	2·83	4·10	2·25	2·91	2·60	3·21	2·92	2·64	2·71	3·07	2·38	2·83	2·89	3·94	2·79	2·77	3·38	3·12	2·96	3·30	3·00
K_2O ..	2·66	2·80	2·49	2·89	3·14	5·64	3·42	3·80	3·22	3·07	2·93	3·96	3·42	5·25	3·94	3·66	4·36	6·40	4·06	4·89	5·32	5·27	4·76
H_2O ..	1·14	2·63	0·62	1·98	1·91	0·68	1·16	1·17	0·88	0·36	1·26	0·12	1·92	0·83	0·93	0·32	0·80	0·75	0·94	0·69	0·85	0·54	0·40
TiO_2 ..	0·90	0·80	0·73	n.d.	tr.	0·40	0·85	0·61	0·59	0·77	0·70	n.d.	0·61	0·25	0·51	0·58	0·46	0·17	0·46	0·20	0·17	0·11	0·20
MnO ..	tr.	tr.	..	n.d.	0·07	0·02	tr.	0·04	tr.	0·03	tr.	n.d.	tr.	0·01	0·14	..	0·09	tr.	0·13	0·15	tr.	0·06	0·11
P_2O_5 ..	0·18	0·18	0·16	n.d.	tr.	0·19	0·09	0·23	tr.	0·02	0·19	0·10	tr.	..	0·18	tr.	0·11	tr.	tr.	0·08	tr.	tr.	tr.
Total ..	100·47	100·85	99·76	99·71	100·70	99·78	99·95	100·38	99·92	100·69	100·75	99·72	99·54	100·87	99·89	99·95	100·21	100·06	99·99	99·97	99·80	100·16	100·43
Specific Gravity	2·75	2·77	2·72	..	2·77	..	2·68	2·65	..	2·66	2·69	2·69	2·71	2·64	2·67	2·68	2·66	2·64	2·64	2·64	2·61	2·62	2·64
Index Number	19·48	19·62	19·88	..	10·71	16·07	9·42	16·74	..	11·68	..	12·40	13·77	7·76	10·20	10·51	7·75	6·25	5·78	3·12	3·59	3·58	2·33

Heavy Mineral Content of the Granitic Rocks.

The heavy mineral assemblages, index numbers and specific gravities of the granitic rocks are set out in Table 5. In most instances, rocks with higher index numbers have greater specific gravities; exceptions are mainly attributable to alteration. It is found that the average specific gravities of the Victorian granitic rocks listed in Table 5 are lower than the averages for granites and granodiorites quoted by Daly (20, p. 47) :—

TABLE 4.

	Range in Specific Gravities (Daly).	Range in Specific Gravities. (Victoria).	Average Specific Gravities. (Daly).	Average Specific Gravities. (Victoria).
Granites	2·516–2·809	2·53–2·69	2·667	2·62
Granodiorites ..	2·668–2·785	2·58–2·76	2·716	2·67

Explanatory Notes on Table 5.

The heavy minerals listed in Table 5 were obtained by crushing representative rock from each locality, and separating in bromoform of 2·88 specific gravity (50, p. 40). The weight per cent. of the heavy minerals (i.e. the index number) was calculated from the weights of the light and heavy fractions. The index number for each granitic rock is not an absolute value, since despite care in sampling and crushing the rocks, clean separations into individual grains could not be always obtained, and during separation into light and heavy fractions in bromoform, larger fragments of light minerals sometimes carried up small attached fragments of the heavy minerals, and heavy minerals sometimes carried down fragments of light minerals. The index numbers obtained are useful for purposes of correlation and differentiation, however, because similar conditions were more or less maintained throughout the heavy mineral separations, and any slight discrepancies affect all the results to similar degrees.

The distribution of the heavy minerals is indicated in Table 5 by means of letters. Similar sets of letters are employed throughout the table, but only those assemblages with similar index numbers possess comparable amounts of any particular mineral species, when the letters are the same in each. For each assemblage *A* (very abundant) indicates a species which is dominantly present, *r* (rare) indicates 7 to 24 per 2,000 grains, and *V* (very rare) represents a species with 1 to 6 per 2,000 grains present. The letters *a*, *C* and *o* represent varying concentrations between the above extremes. This method of representing the mineral concentrations is only partially quantitative, and as Taylor has shown, has its limitations as inaccuracies may arise from personal

TABLE 5.—TABLE OF HEAVY MINERAL INDICES AND ASSEMBLAGES.

GRANITES

Numbers following locality names refer to positions in outcrops on the accompanying map of Victoria	1 BAIRNSDALE (51)	2 WOOROONOOK (101)	3 COLQUHOUN (1B) [GRAY VARIETY]	4 GLENROWAN (49)	5 BORUNG SOUTH (99)	6 COLQUHOUN (1A) [RED VARIETY]	7 NAYOOK WEST (92)	8 BETHANGA (63)	9 WODONGA (84)	10 JUNCTION OF MITTA & BUNDARRAH R. (24)	11 CAPE WOOLAMAI (26)	12 MT. WILLS (25)	13 MT. EMU (34)	14 CAPE EVERARD (59)	15 MT. BUFFALO (2)
ANATASE															
ANDALUSITE		V													
APATITE - COLOURLESS	V		V	V	V	V	o	r	V	o	C	o	o	o	o
" - PALE YELLOW-GREEN															V
" - CORRODED															
" - + PLEOCHROIC CORES											o				V
BIOTITE	V	o	V	C	a	V	C	a	o	a	A	V	A	A	a
CASSITERITE															
CHLORITE		V	C	a	r	a	a		C	o			V	r	C
CORUNDUM															
ENSTATITE															
EPIDOTE			o			C				V	o	V	V		
FLUORITE	V			a		o	V		r	r					V
GARNET	o	C		C		o		V		C		a	V		o
GOLD						V									
HEMATITE	o		V			r				o	o		r		
HORNBLENDE						V			V						
ILMENITE	o			o	V		o		V		V		V	V	V
LIMONITE	C	V		o	C		V			C				o	r
MAGNETITE			V			o				a			V		r
ORTHITE										V					
RUTILE			V								V	V	V		
SPHENE				o			o	o							
SPINEL								V							
SULPHIDES (PYR., PYRRH., CHALCOPYR.)			V	C		r	a	r	r	V		V	V	V	C
TOPAZ													V		
TOURMALINE				o			V					a			V
WHITE MICA	C	a	C		o	C	r	o		o		A	r	C	C
ZIRCON - COLOURLESS	o	r	r	o		V	o	o	r	r	o		C	o	o
" - INCLUSIONS IN	C	o	o	C	r	o	o	r	o	o	o		o	o	V
" - PALE YELLOW	o		V		V	V	V	V	V	o	V		V	V	o
" - ZONED	o	V	V	o		V	r		V		V		V		r
" - "TORPEDO" HABIT		V													
" - CORRODED							V								
ZOISITE					V										
SPECIFIC GRAVITY	2.56	2.61	2.61	2.62	2.63	2.61	2.61	2.64	2.60	2.61	2.65	2.64	2.58	2.62	2.64
INDEX NUMBER	0.56	0.74	1.07	1.53	1.65	1.78	1.76	1.80	2.02	2.27	2.33	2.41	2.68	3.10	3.12

Numbers following locality names refer to positions in outcrops on the accompanying map of Victoria	16 HEATHCOTE (46) [MICROGRANITE]	17 MT. LAR-NE-GERIN (90)	18 DROMANA (17)	19 DERGHOLM (6)	20 DOG ROCKS (13)	21 MT. MITTAMATITE (53)	22 WANGARATTA (44)	23 PYRAMID HILL (65B) [EVEN-GRAINED VARIETY]	24 SOUTH ANAKIES (9)	25 STAWELL (40)	26 GEMBROOK (32)	27 LONGWOOD (81)	28 CASTERTON (37)	29 MT. KORONG (100)
ANATASE			V	V			r				V			
ANDALUSITE								a						
APATITE - COLOURLESS	r	o	o	C	r	V	V	V	C	o	C	C	C	o
" - PALE YELLOW-GREEN												r		V
" - CORRODED		V												
" - + PLEOCHROIC CORES		V	r	C						r	V			
BIOTITE	V	A	C	a	a	a	V	a	a	A	A	a	A	C
CASSITERITE		o												
CHLORITE	A	C	o	r	r	o			r	o	C	o	o	a
CORUNDUM	o						r							
ENSTATITE														o
EPIDOTE	o	o	r	o		C	V				V		C	o
FLUORITE						V						V		V
GARNET				V		C				C	V	r	V	V
GOLD			V											
HEMATITE		o		r			C					r		V
HORNBLENDE	o		C	r	V		V				V	V		
ILMENITE				r			o				r	o	r	V
LIMONITE	o					r	o							
MAGNETITE	C	C	C	C	r	a				r	a			C
ORTHITE										V				
RUTILE														
SPHENE		o	o	r	r	V					r		r	
SPINEL														
SULPHIDES (PYR., PYRRH., CHALCOPYR.)	V		o	r	V		a		r		V	V	V	r
TOPAZ										o	V			
TOURMALINE						V					V	C		
WHITE MICA	r	o		V	a			A	r	V	V	o	o	C
ZIRCON - COLOURLESS	V	r	C	r	r	C	V	o	r	C	C	C	o	V
" - INCLUSIONS IN	V	o	C	C	o	C	C	r	r	C	o	o	o	o
" - PALE YELLOW		r		V	o			V	o		r	r	C	V
" - ZONED			o	o	r	V			V	r	r			V
" - "TORPEDO" HABIT			V					V				V		
" - CORRODED					V				V		V			
ZOISITE	r	r	V								V			o
SPECIFIC GRAVITY	2.64	2.63	2.63	2.63	2.62	2.61	2.33	2.60	2.63	2.63	2.63	2.62	2.67	2.62
INDEX NUMBER	3.25	3.34	3.39	3.46	3.56	3.56	4.29	4.47	4.63	4.64	4.68	4.69	4.69	4.70

A - very abundant. a - abundant. C - common. o - occasional. r - rare. V - very rare.

TABLE 5.—TABLE OF HEAVY MINERAL INDICES AND ASSEMBLAGES—*continued.*

Numbers following locality names refer to positions in outcrops on the accompanying map of Victoria.	GRANITES																													
	BUNYIP. (62)	POWELLTOWN. (88)	ANAKIES. (8)	MAUDE. (66)	EUROA. (80)	BIG HILL, LANCEFIELD. (30B) [COBAW GREEN VARIETY]	SPRINGHURST. (67)	BARRABOOL HILLS.(64)	PYRAMID HILL. (65A) [PORPHYRITIC VARIETY]	GABO ISLAND. (7)	DARRIWIL. (11)	BAYNTON. (60)	TERIP TERIP. (96)	MT. HOPE. (87)	LAKE BOGA. (85B) [GREY VARIETY]	WILSON'S PROMONTORY. (27)	GENOA. (95)	MT. BEENAK. (94)	YOWANG. (12)	PYALONG. (47)	MT. WILLIAM. (56) [COBAW RANGES]	STRATHBOGIE. (70)	HARROW. (76)	BUNGIL. (58)	BIG HILL, LANCEFIELD. (30A) [COBAW WHITE VARIETY]	GARFIELD. (83)	LAKE BOGA. (85A) [PINK VARIETY]	TYNONG. (5)	YOU YANGS. (10C)	MT. WYCHEPROOF. (54)
	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
ACTINOLITE																		V											o	
ANATASE													V																	
ANDALUSITE																								V						
APATITE – COLOURLESS	o	C	o	o	o	C	r	o	o	o	C	C	C	C	o	C	o	o	C	C	C	C		a	C	C	r	C	a	V
" – PALE YELLOW-GREEN				V	V				V			V	o	V		V	V			V	V	r		r					V	
" – CORRODED													V					V											V	
" – + PLEOCHROIC CORES	V	V		V										V		V	r	V										r	V	
AUGITE																										V			r	
BIOTITE	a	A	a	A	A	A	A	A	A	r	a	A	A	A	a	A	A	A	a	A	A	A	A	A	A	A	r	A	A	V
CASSITERITE																X														
CHLORITE	C	o	o	o	C	o	C	C	C	o	a	C	o	C		o	a	o	o	C	a	o		V	o	o		o	r	
DIOPSIDE																													r	
EPIDOTE		V	V							C	V						r						V			V			r	r
FLUORITE		V	V							V			V															V		
GARNET		V	V	V	r	V		V	o	o		V	V	o				V		V	V	V						V		V
HEMATITE															V	r						r	r						r	V
HORNBLENDE	a		V	V						o															o	a		C	C	
ILMENITE	r	C		o	o	V			o			V	V	r				C			V	o		V	V	o		V	o	V
LIMONITE				o																									r	
MAGNETITE			r		V					a	r					V	a		r										r	
ORTHITE				V																								V	o	V
RUTILE			V																							V			r	
SILLIMANITE																								V						
SPHENE	o		r	o							r						V		r						o	o		o	C	
SULPHIDES (PYR., PYRRH., CHALCO.)		V	r						V		o		V	V		V		V	r			V	V					o	r	
TOPAZ							o																			V		V		V
TOURMALINE	r	V			V		a				V	V	V		V	X			V	r		o					C			
WHITE MICA	V	V	r		r	o	C	o	C		r	o	C	C	A	o	o	V	a	C	C	o	a	C		V	A	V	V	A
ZIRCON – COLOURLESS	o	o	o	o	o	C		V	o	C	r	o	o	o	o	C	o	C	r	o	o	C	C	V	C	C		C	a	V
" – INCLUSIONS IN	C	o	r	o	o	o	r	V	o	o	r	o	o	o	o	o	C	o	r	o	o	o	o	V	C	a		a	A	V
" – PALE YELLOW		o	o	V	r	o	V		V		o	V	r	V	V	o	V	r	o		V	r	C	V	V	V		V	r	
" – ZONED	o	V	V	V				V			V		V			V	r	r	V	V	V		V	V	V	o		o	a	
" – "TORPEDO" HABIT					V							V	V	r			V			V	V	V							r	
" – CORRODED		V	V							V		V	V		V	V		V		V	V					r			V	
ZOISITE			V	V			r				V								V						V	V				
SPECIFIC GRAVITY	2.64	2.64	2.63	2.85	2.66	2.64	2.66	2.62	2.85	2.64	2.63	2.85	2.63	2.65	2.62	2.66	2.82	2.66	2.63	2.65	2.65	2.66	2.57	2.66	2.64	2.66	2.65	2.64	2.65	2.66
INDEX NUMBER	4.76	4.61	4.86	4.94	5.05	5.06	5.24	5.35	5.81	5.76	5.87	5.69	6.07	6.25	6.25	6.28	6.45	6.51	6.52	6.66	6.74	6.77	6.45	8.66	9.32	10.09	10.14	10.32	13.04	13.44

A–very abundant. a–abundant. C–common. o–occasional. r–rare. V–very rare. X–recorded in thin sections or in the field only.

TABLE 5.—TABLE OF HEAVY MINERAL INDICES AND ASSEMBLAGES—*continued.*

Numbers following locality names refer to positions in outcrops on the accompanying map of Victoria.	ADAMELLITES				GRANODIORITES																				
	INGLISTON. (35)	BROADMEADOWS. (16)	TRAWOOL. (15)	MARYSVILLE. (14)	MALDON. (20)	Mt. MARTHA. (19)	Mt. LEINSTER. (41)	ZUMSTEIN'S CROSSING, GRAMPIANS. (23)	OLIVER'S HILL, FRANKSTON. (61)	KERRISDALE. (39)	LIMESTONE CREEK. (75)	GONG GONG, BALLARAT. (42)	HARCOURT. (31)	BULLA. (36)	ORBOST. (45)	Mt. BULLER, NEAR MERRIJIG. (3)	MORANG. (21)	Mt. ELIZA. (18)	BIG HILL, BENDIGO. (28)	ARARAT. (78)	BARINGHUP. (29)	MAJORCA. (73)	NARRE WARREN. (74)	TINTALDRA. (55)	Mt. ERICA. (98)
	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84
ANDALUSITE							X											V							
APATITE—COLOURLESS	C	a	a	o	C	C	C	o	C	C	a	C	C	a	C	o	a	C	a	C	a	o	C	o	C
" —PALE YELLOW-GREEN	V	r	r		r	V				r	V			o	V		V							V	
" —CORRODED																				V					
" —+PLEOCHROIC CORES				V	V	V	V	o	V		V		V					V	o	V	r	V	V		
BIOTITE	A	A	A	A	A	A	A	C	A	A	A	A	A	A	A	C	a	A	A	A	A	A	A	A	A
BROOKITE														V											
CHLORITE	a	o	V	r	C	V	o	r	o	C	C	C	C	A	o		o	o	o	o	o	r	C	a	o
CORUNDUM	V																V								
EPIDOTE		r		r			o		V	V	r	V	r		r	V			V	r		V	r		
FLUORITE					V			V					V												
GARNET	r	V	o	o	V	V		V		C			V	o			o	o							
GOLD		V																							
HEMATITE						r											r								
HORNBLENDE						o	o	C	r		C	r	V		C	A	o	a		a			o		a
ILMENITE	r	o				r			C	r		V	V	r	o	r	o	r					V	r	V
LIMONITE				V		V		o		r						V		V		o					
MAGNETITE	V	V	V	V	r	r	a	a			a					a		V		a					
MOLYBDENITE					C																				
ORTHITE								V									V	V							
RUTILE		o				V				V															
SPHENE				r	V	V	r	o			o	o			o	o		o		o	V		o		
SULPHIDES (PYR., PYRRH., CHALCOP.)	r	o	V	V	r	r	V	V				o	o	r	o	a	o	o	V				o		V
TOURMALINE		V	V	r				V		a			V					V						o	
WHITE MICA		o	r		V					C			V	C	V					V			V	C	
ZIRCON—COLOURLESS	C	C	a	o	C	C	o	C	C	C	C	C	C	C	o	C	C	C	o	C	o	o	C	o	C
" —INCLUSIONS IN	o	o	r	o	r	C	C	o	C	o	o	a	o	r	o	C	C	C	C	C	o	o	o	o	o
" —PALE YELLOW		C	o	V	V	V		r		o	V		V	V			V		V	o	V	V	V	V	V
" —ZONED	V			o	r	o			o		V	C	V	V	V	V	C	V	V	r	V	r	r	o	V
" —PYRAMIDAL	V	V						V																	
" —"TORPEDO" HABIT	V	V	r	o			V			r	V			C	r						V			r	V
" —CORRODED								V		V				V											
ZOISITE																V		V							
SPECIFIC GRAVITY	2·61	2·67	2·66	2·58	2·65	2·56	2·64	2·64	2·64	2·67	2·70	2·67	2·66	2·69	2·62	2·69	2·64	2·70	2·65	2·64	2·66	2·70	2·67	2·71	2·72
INDEX NUMBER	7·75	9·42	10·20	17·65	5·40	7·12	7·76	7·78	6·28	8·36	9·47	10·21	10·51	10·71	11·26	11·59	11·68	12·40	12·68	13·29	13·32	13·38	13·56	13·77	13·67

A—very abundant. a—abundant. C—common. o—occasional. r—rare. V—very rare. X—recorded in thin sections or in the field only.

TABLE 5.—TABLE OF HEAVY MINERAL INDICES AND ASSEMBLAGES—*continued.*

Numbers following locality names refer to positions in outcrops on the accompanying map of Victoria.	GRANODIORITES																PORPHYRIES				APLITES			DIORITES	
	MT. DRUMMER. (48)	MT. BALDHEAD. (82)	SELBY. (79)	TARNAGULLA. (52)	YACKANOANDAH. (71)	EVERTON. (77)	MARYSVILLE. (57)	POWELLTOWN. (93)	MONBULK CREEK. (43)	HEALSVILLE. (22)	TAWONGA. (86)	UPPER BEACONSFIELD. (97)	BRAEMAR HOUSE, MACEDON (38)	BEECHWORTH. (72)	WARBURTON. (33)	SMALL HILL, BUCKRABANYULE (89)	MT. TAYLOR. (4)	BUXTON. (68)	YOU YANGS. (108)	DROMANA. (178) [GRANOPHYRE]	WARBURTON. (69)	YOU YANGS. (10A)	STRATHBOGIES. (50)	GRANITE FLAT. (91)	OROMANA. (17c)
	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109
ACTINOLITE							o					V							o						
ANATASE																		V							
ANDALUSITE																					a				
APATITE – COLOURLESS	o	o	C	a	C	C	o	C	C	C	C	C	C	C	C	C	o	o	C	o	r	V	V	o	o
" – PALE YELLOW-GREEN									V	V						r	r								
" – CORRODED								V						V						r					
" – + PLEOCHROIC CORES	V			C			V	V	V																r
AUGITE																			r					C	
BIOTITE	a	A	A	A	A	a	A	A	A	r	a	A	A	A	A	A	a	a	A	C	a	A	o	a	C
CASSITERITE						X																			
CHLORITE	o	r		o	o	r	o.	o		A	o	V	a	o	A	o		C	o	r	V	o	o		r
EPIDOTE	a	o			r	V				V	o		r	r			o							r	
FLUORITE						V											C								
GARNET				V	V			V		r					V		a	a							
HEMATITE						o							o			o		o				r			r
HORNBLENDE	A	a	A	a		a	o		a			a			r				C	o		r		A	A
HYPERSTHENE													r		o									o	
ILMENITE	V		V		V			V		o		o			o	r		C	C	C					o
LIMONITE								r					o				r		o	a		r			
MAGNETITE	a	a				a	V			r	C		C									r		a	
MOLYBDENITE						C																			
ORTHITE			V	V	V																				
RUTILE						V														r					
SILLIMANITE							X																		
SPHENE	o	o	C	o	o	C	r	V	r			V		C		o			o						r
SULPHIDES (PYR., PYRRH., CHALCOP.)	o	r			V	r	r	o	o	o			o	V	r		r		r					V	
TOURMALINE					V	X	V	V		r			V					o			r		A		
WHITE MICA	o	r		V						o	A	V		r		C					o		C		
ZIRCON – COLOURLESS	o	o	o	o	C	r	o	o	o	C	r	o	C	o	o	o	C	C	C	C	V	o	V	V	o
" – INCLUSIONS IN	o	o	o	C	r	r	o	o	o	r	o	o	o	o	r	r	V	V	a	o	r	o	r		o
" – PALE YELLOW		V						V					V		V	r		V		r	V		V		
" – ZONED		V	V	V		V		V	V					V	V				C	r		r			
" – PYRAMIDAL								V							V					V					
" – "TORPEDO" HABIT								V		o	V				V	o					V				V
" – CORRODED								V					V		V				V		V				
ZOISITE	r							V			V		r		o		a							V	V
SPECIFIC GRAVITY	2.73	2.72	2.72	2.75	2.70	2.66	2.65	2.72	2.76	2.65	2.75	2.75	2.66	2.69	2.72	2.71	2.58	2.66	2.64	2.64	2.60	2.59	2.60	2.61	2.56
INDEX NUMBER	14.58	15.33	15.45	16.01	16.07	16.71	16.74	16.90	17.29	16.26	16.33	19.46	19.62	19.66	19.66	24.75	4.73	9.40	11.40	2.71	2.09	4.05	4.26	30.49	39.30

A–very abundant. a–abundant. C–common. o–occassional. r–rare. V–very rare. X–recorded in thin section or in the field only.

errors when the minerals are classed into such categories (as in Table 5) by eye estimation, instead of by the method of counting grains (71, p. 687).

The letters accompanying similar numbers after the locality names at the head of the table, refer to different rock types from the same area.

The Grouping and Origin of the Heavy Minerals.

The heavy minerals are grouped into (A) heavy essential minerals, and (B) heavy accessory minerals. The heavy essential minerals are ferromagnesian silicates, which, because of their variation in granitic rocks, Marsden considers should be excluded when correlating such rocks by heavy mineral methods (47, p. 134). They are included here, however, because of their influence upon the index numbers, and because they are frequently of use in comparing and distinguishing isolated granitic outcrops. A sudden rise of index number in the granitic rocks is invariably due to increase in ferromagnesian minerals as has also been found by Groves (35, p. 472).

The heavy accessory minerals are those which are present in such small quantities that they are best studied by methods involving concentration rather than by thin section methods (76), and they have been subdivided into groups in Table 6 on their probable modes of origin. Combining the ideas relating to the genesis of the various heavy mineral species (51, 54, 72, 77, etc.), and using Wells' classification (73) as a basis, the heavy minerals obtained from Victorian granitic rocks are grouped as follows.

Table 6.

A. Heavy Essential Minerals—biotite, hornblende, white mica.

B. Heavy Accessory Minerals—

1. Normal or primary minerals (developed independently of a high flux content, and usually early products of crystallization)—
   apatite, zircon, ilmenite, magnetite, rutile, gold, pyrite, pyrrhotite (and some sphene, orthite, andalusite and sillimanite).
2. Pneumatolytic minerals (developed by flux concentration, and formed late in the cooling history of a magma)—
   tourmaline, topaz, fluorite, brookite, molybdenite, pyrite, anatase, cassiterite (and some rutile and apatite).
3. Products of Contamination (developed by the addition of foreign material and formed as products of assimilation or introduced as xenocrysts)—
   andalusite, garnet, sillimanite, diopside, augite, corundum, hypersthene, actinolite, spinel (and some orthite and sphene).
4. Secondary minerals (produced by weathering or replacement, and formed at the expense of the primary minerals)—
   epidote, zoisite, chlorite, hematite, limonite, leucoxene (and some white mica and sphene).

This grouping has its limitations, because it is impossible to tell in contaminated granitic rocks how much of the biotite and hornblende is primary, and how much is due to contamination. Groves (33, p. 224), Brammall (10, p. 45), Stark and Barnes (64, p. 348) and Grantham (32, p. 306), all regard a certain amount of the hornblende in granitic rocks examined by them as being derived from the assimilation of foreign rocks. The author has indicated a similar mode of origin for some of the hornblende at the You Yangs (1) and at Dromana (3).

Biotite and hornblende have most effect on index number variation in Victorian granitic rocks. The hornblende is more abundant in granodiorites than in granites, and is usually subordinate to biotite, although in the Selby granodiorite, these two minerals are present in approximately equivalent proportions. High biotite content in the Victorian granitic rocks is usually accompanied by a low percentage of hornblende. The paucity of these two minerals in one granite compared with another may mean that one is less contaminated.

White mica occurs in some of the granitic rocks as a primary constituent (muscovite) as at Springhurst, Mt. Korong, Lake Boga, Pyramid Hill, Mt. Wills, Wooroonook and Mt. Wycheproof. In others, it is secondary and developed from the alteration of cordierite, or is bleached biotite.

Among the heavy accessory minerals, sphene may be primary or secondary or a product of contamination, and the relative abundance of these types cannot be determined in the heavy assemblages or in thin sections. Groves (33, p. 224) and Wells (73, p. 260) concluded that much of the sphene in granitic rocks is due to assimilation, although Boos (8) and Brammall and Harwood (12) have described occurrences where it is secondary. Sphene is regarded as one of the chief diagnostic minerals in heavy residues by McAdams (48), but is not of such importance in Victorian granitic rocks on account of its threefold mode of origin (see Table 6). It occurs more commonly in granodiorites than in granites, and more abundantly in hornblende-rich types.

The rare occurrences of gold in Victorian granitic rocks probably have a similar origin to those at Dartmoor, England, where scattered specks are regarded as primary (9, p. 253). A pyrogenic origin is conceded for rutile at Dartmoor by Brammall and Harwood (11, p. 205). As there is no evidence of any other mode of origin of this mineral in Victorian rocks, it is classed with the primary accessories; it is as rare in Victorian as in British granitic rocks (33 and 46). Since anatase and brookite are regarded as having been formed during pneumatolysis (13, p. 22), they are here classified as pneumatolytic accessories as has been done by Wells (73) and Taylor (70). Anatase may be a secondary accessory, however, as shown by Smithson (61), but since both anatase and brookite are very rare in Victorian granitic rocks (see Table 5), only a few grains of anatase and one grain only of brookite having been noted throughout the assemblages, the mode of origin is indefinite.

The sulphide minerals occur in several groups of the heavy accessories in granitic rocks. In a few Victorian granitic rocks (e.g. Merrijig), pyrite along joint planes is of pneumatolytic origin, likewise pyrrhotite in granodiorite from Morang. Widely scattered grains of pyrite in many of the granitic rocks are primary, being remote from any visible veins in rocks unaffected by pneumatolysis, and are thus comparable with occurrences in the Shap granite in England (32, p. 305).

Andalusite of both contamination (16, p. 225) and of pyrogenic origin (38), has been recorded in Victorian granitic rocks, while corundum is known in Victoria as a product of contamination at the You Yangs (1) and at Powelltown (6). Garnet in acid plutonic rocks has been regarded as a product of assimilation (1, 12, 24, 26, 37, 68 and 73), and it is therefore grouped here among the contamination accessory minerals although Brammall and Harwood record some garnet as primary (15, p. 52). Hypersthene has been recorded from Scottish granites as occurring under conditions that exclude contamination by basic rocks (46, p. 32), but is classed with contamination accessories in Victorian granitic rocks because where present it occurs as xenocrysts derived from the incorporation of dacite xenoliths. This mineral is primary, however, in a two-pyroxene quartz diorite from Granite Flat in Victoria (27).

Most of the orthite (allanite) in Victorian granitic rocks is of contamination origin, but some occurrences are probably primary (2). Spinel is grouped with the primary accessories by Niggli (52, p. 15), but this genesis is considered from its occurrence in basic rather than in acid rocks, since spinel crystallizes from a magma low in silica. In granitic rocks, spinel is a contamination accessory mineral, developing near contacts with wall or roof rock (73), and meagre occurrences of this mineral as xenocrysts or as armoured relics associated with sillimanite in cordierite crystals (e.g. as in the Piper's Creek granite near Kyneton), are known in Victoria.

The method of grouping the remaining minerals in Tables 5 and 6 requires no further comment, since their modes of origin in the crystallization of granitic magmas are generally accepted.

Zircon is the most abundant and most widespread of all the accessories in Victorian granitic rocks, being equally developed in granites and granodiorites. Some varieties like the coloured, the zoned (14 and 19), and the corroded crystals (75), as well as those containing inclusions (17) and types with a "torpedo" habit (1 and 45), are listed in Table 5. In addition to these, rare acicular crystals occur at Powelltown (in the granite) and at Navook West (6), distorted crystals (31 and 53) at Tynong and Mt. Beenak, parallel growths (34) at Cape Everard, Mt. Beenak, Longwood, Yackandandah and the You Yangs (1, p. 130, fig. 2D), pyramidal crystals and stout, stumpy crystals at Mt. Eliza, the You Yangs (1) and Oliver's Hill near Frankston, and rare crystals with outgrowths (18) at Gong Gong near Ballarat and Big Hill near Bendigo. Most of the zircons show the normal crystal forms (110 and 111): rare rounded (water-worn) examples are probably xenocrysts.

Apatite is next in abundance to zircon among the primary accessory minerals. It is more common in granodiorites than in granites, and is frequently of greater abundance in hornblende-rich types. The presence of corroded crystals of apatite among the heavy mineral assemblages, indicates that apatite is sometimes attacked during the magmatic history of a rock (55, p. 218), and is therefore not as stable an accessory constituent of granitic rocks as suggested previously (33). In some assemblages, the occurrence of small apatites as clear rods and grains without inclusions, as well as fragments of larger crystals of apatite with few inclusions, and sometimes with corroded faces, may indicate two generations within the same rock. About a third of the granitic rocks examined contained apatite crystals with coloured (pleochroic) cores (4 and 62), and these are listed in Table 5. Apatite becomes subordinate in Victorian granitic rocks with increase of fluxes, and if present as a common constituent in the same rock as white mica, the latter is invariably the variety derived from the bleaching of biotite, as in the granodiorite from Tawonga.

Of the iron ore accessories, ilmenite is more common in the granodiorites than in the granites, but is never abundant in any one assemblage. Magnetite is less widely spread than ilmenite, but is more abundant in certain individual samples, especially hornblende-rich rocks. Magnetite and ilmenite are never abundant together in the same assemblage, if one is common the other is subordinate or wanting.

A characteristic feature of the heavy mineral assemblages obtained from hornblende-rich granitic rocks is the marked occurrence of epidote, sphene, magnetite or ilmenite (usually magnetite), and greater quantities of apatite. This association is most pronounced among the heavy mineral assemblages of granodiorites in which hornblende is recorded as abundant or very abundant (see Table 5), and in which the index numbers exceed 11. Such granodiorites are therefore richer in lime and iron than the normal granodiorites, and the occurrence of epidote or secondary sphene, or both, indicates considerable late magmatic changes.

Pneumatolytic accessories in Victorian granitic rocks are more abundant and more varied in the granites than in the granodiorites, but no assemblage has a comparable wealth of pneumatolytic minerals as is contained in the Eskdale granite of Cumberland, England (56). They are regarded as next in importance to the stable primary accessory minerals for correlating granitic masses (33, p. 235). Tourmaline is the most widespread, being sufficiently common in a few examples to be classed as an auxiliary mineral (42, p. 28). Cassiterite was only recognized in the assemblage of the Mt. Lar-Ne-Gerin granite, but has been recorded in the field from Everton (23, p. 15) and Wilson's Promontory (29 and 58). The remaining pneumatolytic accessories are confined to a limited number of Victorian granitic rocks, and are seldom well represented in any one.

Relationship of Index Number to Composition.

The relationship between index number and composition of chemically analysed Victorian granitic rocks is indicated in fig. 2, where the full circles represent granodiorites (including the so-called adamellites), and the full squares represent granites.

The results show a direct relationship between chemical composition and index number. FeO, TiO_2, CaO, MgO and Al_2O_3 increase with rise of index number while SiO_2 decreases. The index number is of value in the granitic rocks in providing quantitative data of the relationship between heavy (i.e. mostly ferromagnesian) and light (i.e. mostly quartz and felspar) minerals, and is regarded as useful for purposes of comparison or correlation, and for the detection of contamination and differentiation (33, p. 236). Consequently by reference to fig. 2, the heavy mineral index number provides a basis for estimating the approximate chemical composition of an unknown specimen.

Range of Index Numbers of the Granitic Rocks.

The ranges in the index numbers of all the granitic rocks analysed by heavy mineral methods, are set out in fig. 3, where separation into different categories is based on the classification of the rocks from thin section studies, micrometric analyses and chemical analyses.

The range in the index number for aplites (2·1 — 4·3) is about centrally placed with respect to the range for normal granites (0·6 — 7); these are high values for aplites generally, because those examined are special types containing an abundance of andalusite or tourmaline. Normal aplites have smaller index numbers ranging as low or lower than the least value for the granites.

The index number increases as the normal granites pass laterally into a region of contaminated granites (7 — 13·5). Varieties of the granitic rocks originally regarded as adamellites have index numbers comparable with either those of contaminated granites or with those granodiorites with the lower index numbers. These so-called adamellites fall into a group representing transition types between true granites and granodiorites proper. The index numbers of the granodiorites are still higher and range towards, but do not reach the values for diorites. As in the granite group, higher index numbers result from contamination of the granodiorite magmas by assimilation of foreign material. The index numbers of two dioritic rocks included in

Graphs showing the Relationship between Index Number and Chemical Composition. (Letters on diagram refer to the same rocks as in Table 3.)

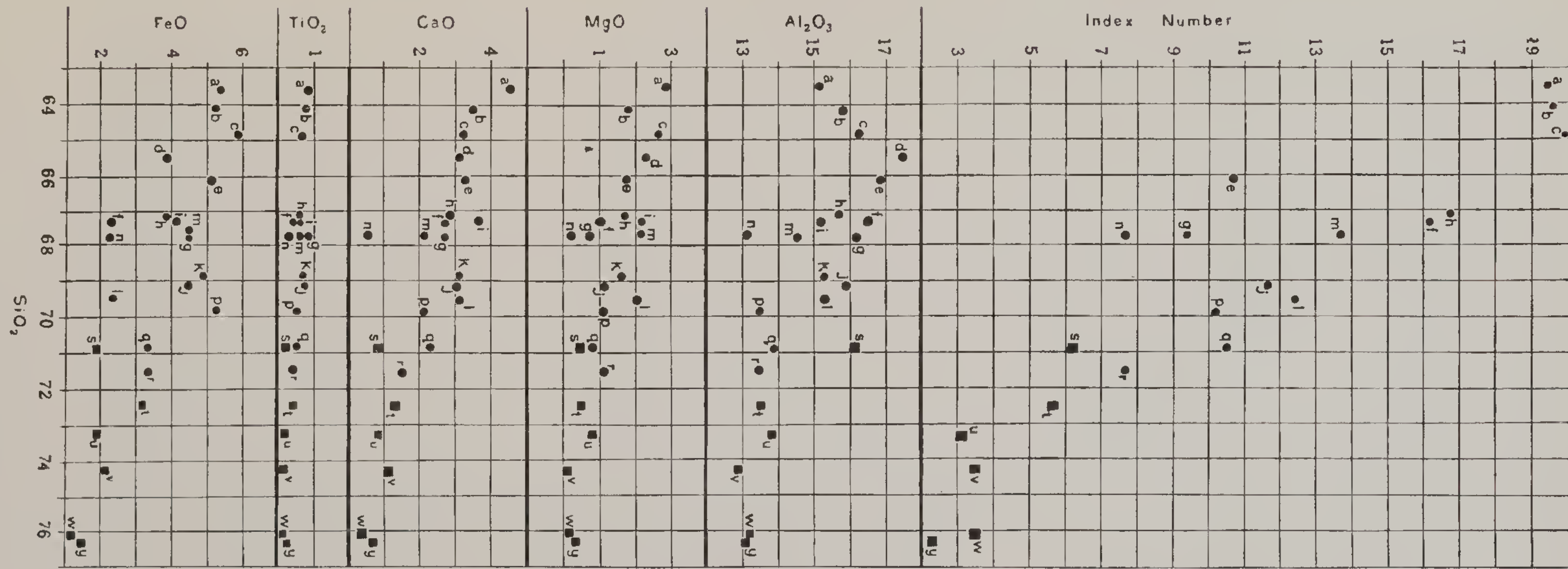

Fig. 2.

fig. 3, show sudden increases upon the values for granodiorites, owing to their greater percentages of essential, primary ferromagnesian minerals.

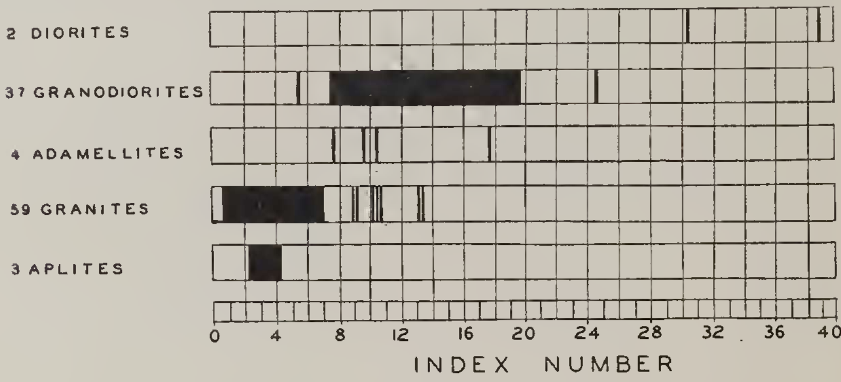

FIG. 3.—Diagrammatic representation of the range of index numbers of some Victorian granitic rocks.

Index numbers over 7 in Victorian granites (e.g., You Yangs, Tynong and Garfield), and over 15 in granodiorites (e.g. Powelltown, etc.), indicate considerable contamination. In the Buckrabanyule outcrops (index number = 25) for instance, the high value of the index number is due to a local concentration of ferromagnesian minerals, and is higher than in other parts of this intrusion. It thus represents a contaminated portion (39, p. 220) and has dioritic affinities. Of the other contaminated granodiorites in Victoria that were investigated, the index numbers do not reach 20, and there is thus a considerable gap between them and the lower figures for diorites. Rocks with index numbers between 30 and 40 in Victorian igneous intrusions, are true diorites.

Deductions from the Heavy Mineral Analyses.

Investigations by previous workers in the province of heavy minerals show that the nature of the heavy minerals and their distribution in granitic rocks, depend upon such factors as the original composition of the magma, the stage of differentiation attained, the types of intruded country rocks and the amount of assimilation and sinking of contamination products. A study of the heavy mineral suites of granitic masses therefore assists in determining whether granitic masses are comagmatic or unrelated, to what extent they have been contaminated, and in some instances what types of rocks were absorbed into the magmas. Comagmatic masses should possess similar primary heavy minerals, and higher index numbers would be obtained nearer the roofs of intrusions if appreciable assimilation had occurred and provided that sinking of contamination products was not great. If heavy materials added to the granitic magmas had sunk to any great extent, higher index numbers should occur in lower levels of the intrusions, although at depth, the attainment of equilibrium will probably have removed excesses such as those in evidence nearer contacts with country rock. The content of pneumatolytic heavy accessories, frequently missed in thin section examinations when scarce, indicates whether or not the intrusions were rich in mineralizers, but as fluxes concentrate near the roofs of intrusions, the absence of pneumatolytic accessories from any outcrop may be a direct consequence of deroofing, and therefore not then attributable to an original sparsity of mineralizers.

An examination of the effects of these processes upon those Victorian granitic rocks analysed by heavy mineral methods, results in the following observations:—

Contamination Effects.—The contamination of many Victorian granitic rocks is indicated by their content of xenoliths, by the occurrence of high index numbers, and by the presence of contamination accessory minerals. These three factors, although intimately dependent upon one another, are not necessarily all pronounced in the one rock type. Thus among the contamination accessories, the mineral garnet, although rare, is widespread in the heavy mineral assemblages of the Victorian granitic rocks, but all rocks with garnet do not have high index numbers (see Table 5). The prominence of ferromagnesian minerals in some examples results in increased index numbers, and although such granitic rocks may sometimes contain abundant xenoliths, heavy contamination minerals added to the magma may not be distinctive as such in the assemblages, since they may have been made over to mineral species comparable with those already crystallizing from the magma. In such examples, contamination results in the addition of unknown amounts of minerals like the ferromagnesian silicates. Even though some of the granitic rocks have low index numbers (see Table 5), and would therefore appear to be only slightly contaminated, several of them contain foreign xenoliths in various stages of mechanical disintegration and chemical digestion. Their low index numbers probably result from the continual removal of excess foreign material by convection currents within the magmas. In general, however, the granitic rocks with the greater index numbers contain more xenoliths than those with lower index numbers, except for special examples to be discussed later under Pneumatolysis. From xenoliths incorporated in the granitic magmas, minerals such as biotite, hornblende, sphene, orthite, garnet, diopside, augite, hypersthene, corundum, waterworn zircons, andalusite, sillimanite and iron ores are added to the magmas as xenocrysts by mechanical disintegration or as products of chemical digestion.

Some Victorian granitic rocks contain numerous xenoliths, some have fewer xenoliths but high index numbers (excluding those due to pneumatolysis), and others have contamination accessories but low index numbers with few remnants of xenoliths. It is therefore concluded that the majority of them have been subjected to contamination by the addition of foreign material; some like the You Yangs, Tynong and Garfield granites to greater extents than others. Contamination is probably the main factor governing the variability of index number in Victorian granitic rocks.

Variation of index number within the same plutonic body is sometimes due to contamination by assimilation, as shown by Groves in the Channel Islands granites (33, p. 224). From present knowledge of heavy mineral relationships in Victorian intrusions, there is only one, the You Yangs granite (1), that shows evidence of greater assimilation at the margins and in higher portions. This is reflected in the index numbers which are generally greater at higher than at lower altitudes for central portions of the outcrop, and greater nearer the edge of the mass than in central parts at the same level.

Differentiation Effects.—Associated with contamination, the extent to which differentiation and sinking of earlier formed primary minerals or later formed contamination products have occurred also play an important part in the variation of index numbers and species represented in heavy mineral assemblages, both between different intrusions and within the confines of the same plutonic body. The degree to which this factor has operated in the Victorian granitic rocks, cannot at present be gauged.

Pneumatolysis Effects.—Flux concentration is sometimes an important factor in influencing index numbers and mineral assemblages in granitic rocks, and the occurrence of index numbers greater than the normal in granites, does not therefore always imply considerable contamination. In the Mt. Wycheproof granite for instance, the index number (13·4) is 8·5 above the average (4·9) for Victorian granites, and is due to the abundant development of white mica of slightly greater specific gravity than that of bromoform in which the heavy mineral separation was carried out.

Pneumatolytic accessory minerals in the Victorian granitic rocks are usually of insufficient abundance to produce marked variations in their index numbers, although they are partially responsible for index number variations at Pyramid Hill and in the Futters Range.

Comparisons of Related Groups of Granitic Rocks.

The comparisons of the following groups of granitic rocks are based mainly on their heavy mineral assemblages and index numbers, but their appearance in the hand specimens, examinations of thin sections, and their micrometric and chemical analyses where available, as well as certain field characteristics in some instances, have also been taken into consideration.

Relationships of Separated Masses.

Similarities.—The most striking resemblances among separated outcrops of Victorian granitic rocks occur in the group of granodiorites associated with the dacite lavas of late Palaeozoic age in Central Victoria. Pronounced similarities in the heavy mineral assemblages exist between the granodiorites from Macedon, Healesville, Warburton, and Upper Beaconsfield, so that in support of other evidence (25, 26 and 43), the heavy mineral study of these types indicates development from a common magma and similarities in the intrusive histories. Allied types with somewhat lower index numbers at Monbulk Creek and Marysville have similar heavy mineral assemblages with minor variations.

Separated granitic masses that show some similarities occur in South-Central Victoria at Bulla, Morang, and Broadmeadows. The index numbers of these outcrops are comparable, and many of the heavy minerals are alike and about equally developed in each (see Table 5). In addition it has been stated that the Bulla and Broadmeadows rocks are associated chemically and mineralogically (41, p. 336). The occurrence of fresh and altered cordierite in both of these rocks indicates assimilation of similar rocks (Silurian shales). Similarities in these granodiorites suggests that they may be comagmatic, and any variations result from slight differences in the intrusive histories.

Earlier studies of thin sections and hand specimens of granodiorites led to the suggestion that similarities exist between outcrops at Macedon and Harcourt (60, p. 19), while the Mt. Eliza and Mt. Martha granodiorites are said to resemble the rock from Harcourt (44, p. 5). Although hand specimens of these rocks may superficially resemble one another, the examination of their index numbers and the variation in the heavy mineral assemblages (see Table 5) indicate that there are greater contrasts than similarities. The Harcourt rock (Mt. Alexander quarries portion), however, resembles the Bulla granodiorite in heavy mineral percentage, in the amounts and varieties of the primary accessories, and in the secondary minerals. Hand specimens are also alike, and the rocks at both localities contain xenoliths of sedimentary origin in similar stages of reconstitution.

Among some of the granitic rocks it is found that analogous index numbers occur for widely separated outcrops such as from Wilson's Promontory in the south and Mt. Hope in the north of Victoria, also granodiorites from Mt. Leinster in Eastern Victoria and Zumstein's Crossing in Western Victoria. Except for the total amounts of the heavy minerals being identical, there are no similarities in original composition for either the two granites or the two granodiorites.

Variations.—Outcrops of granite situated close to one another north-east of Geelong, show pronounced variations in the heavy mineral assemblages and index numbers. The differences result from unequal amounts of de-roofing of the separated masses, and variations in the degree and nature of assimilation. The primary accessory minerals indicate that the separated outcrops are otherwise genetically related (1).

The neighbouring granitic masses in the Mornington Peninsula show variations in index numbers and heavy mineral assemblages as well as in other features. A study of these variations indicates that each of the outcrops at Oliver's Hill near Frankston, Mt. Eliza near Mooroouduc, Mt. Martha and Arthur's Seat near Dromana had different intrusive histories, and that the main factors producing existing rock types were the degree of differentiation attained and the types of rocks assimilated into the magmas (3).

A group of neighbouring granitic outcrops in Western Victoria, at Mt. Lar-Ne-Gerin, Stawell, Ararat and Zumstein's Crossing, show wide divergences. Apart from the first two being granites and the other two granodiorites, they all differ in index numbers and mineral assemblages, as well as in appearance of hand specimens and thin sections. The conclusion is that all had different intrusive histories and were derived from different sources. In like manner, separated outcrops at Dergholm, Harrow, and Casterton in far Western Victoria bear little relationship to one another. Outcrops at Bethanga and Wodonga in North-Eastern Victoria are not widely separated and have comparable index numbers. The heavy mineral assemblages, however, contain significant differences such as the presence of certain mineral species in one which are absent from the other, and variable amounts of those species common to both (see Table 5). These variations indicate probable differences in the compositions of the original magmas and in the intrusive histories.

Relationships Within the Same Mass.

Similarities.—A number of samples selected from different localities in the Cobaw granitic massif in Central Victoria have closely analogous index numbers and heavy mineral assemblages. Samples from Mt. William, Baynton, Pyalong and two from Big Hill near Lancefield are all near the margin of the mass. They all have low index numbers which, in conjunction with the similar heavy mineral assemblages, rarity of xenoliths and other analogies, indicate that the exposure is a relatively uniform one. As pneumatolytic accessories are absent, the uniformity suggests that the Cobaw granitic mass has probably been subjected to extensive de-roofing, and a level in the intrusion has been reached where local excesses due to contamination have been removed. Minor variations exist, however, which must be attributed to slightly greater assimilation effects, the traces of which have not been eliminated by erosion. These minor variations are the occurrence of a larger index number for one of the Big Hill samples, and the presence of local development of cordierite containing spinel in the Piper's Creek granite in the Kyneton district.

Variations.—In the batholith extending eastwards from Gembrook (6), samples from Powelltown, Bunyip and Gembrook have comparable index numbers and heavy mineral assemblages, but in the southern portion of the outcrop higher index numbers at Tynong and Garfield are due to greater assimilation of foreign material, and at these two localities xenoliths and basic schlieren are more abundant than in the other samples examined (2). Similar primary aceessory minerals indicate that the original magma was uniform in character, but variations in the amounts of ferromagnesian minerals and in the distribution of xenolithic material, indicate different degrees of assimilation in different parts of the intrusion.

In the Strathbogies granitic mass, there is a general increase of index number in a southerly direction from Euroa (5·05) and Longwood (4·69) in the north, to Strathbogie (6·77) further south-east, and Kerrisdale (8·36) and Trawool (10·20) in the south-western extremity of the outcrop. At Terip Terip, east-north-east of Trawool, the index number is lower (6·07). Variations are due more to the amounts of each heavy mineral present than in the species represented, and as the primary accessories are similar, an originally uniform magma is indicated. The abundance of cordierite in these rocks (5) supports the conclusion that contamination is responsible for the variable index numbers, and that assimilation of shales in large quantities has occurred over a wide area. Variability in the amounts of material assimilated has resulted in the formation of contaminated granites which in parts have distinctly granodioritic affinities as at Kerrisdale.

Similar variations in the same outcrop of granodiorite occur at Limestone Creek and Mt. Leinster where the mineral assemblages are similar but the index numbers differ, due to greater development of hornblende at Limestone Creek. In the Powelltown-Warburton mass of granodiorite, differences in the index numbers are due to variable amounts of biotite resulting from the assimilation of different rock types (6). Granodiorite at Mt. Erica (7), 20 miles east of the Powelltown-Warburton mass, and separated from it by a later granite intrusion, is probably comagmatic with the Powelltown and Warburton occurrence, because the primary minerals are identical. Variations in the index numbers and heavy mineral assemblages are due to divergences in the late magmatic history, when garnet and chlorite were formed at Powelltown and Warburton, while more hornblende than biotite was developed at Mt. Erica.

In the granodiorite mass of the Lysterfield Hills, south of the Dandenong dacites, different index numbers at Narre Warren (13·56), Selby (15·45), Monbulk Creek (17·29) and Upper

Beaconsfield (19·48) are due essentially to variations in the content of hornblende and biotite, most probably brought about by variable amounts of assimilation.

Samples of granodiorite from the granitic mass in which Harcourt is situated show considerable ranges in the index numbers but the heavy mineral species in rocks from Maldon, Baringhup, Harcourt and Big Hill south of Bendigo are generally comparable, the main differences being in the amounts of each present. The similar index numbers and heavy mineral assemblages of the granodiorite outcrop east of Majorca and that of the Baringhup area, indicate that the Majorca occurrence is comagmatic with the main Harcourt mass.

In the Futters Range, the index number of the Wangaratta granite in the central portion is three times as great as that at Glenrowan in the south. The only common attributes of these two heavy mineral assemblages are the abundance of iron sulphides and the scarcity of apatite; the major variations in heavy mineral content can be gauged from columns 4 and 22 in Table 5. Although only eight or nine miles apart in the same mass, these two examples show considerable diversity in heavy mineral characteristics, mainly as a consequence of pneumatolysis.

Age Relationships of the Granitic Rocks.

Many of the Victorian granitic rocks are regarded as Devonian to post-Carboniferous in age (57 and 58). Some evidence of the relative age relationships of the granitic rocks of this period of magmatic activity can be obtained from their heavy mineral analyses. In the Cornish granites of England, Ghosh found that younger granitic types contained lower percentages of heavy minerals than older types (30). Where known intrusive contacts occur between older and younger granitic rocks in Victoria, a similar relationship is discovered. Thus at Tintaldra where granite invades granodioritic rock (28), at Powelltown where granite intrudes granodiorite (6), and at Pyramid Hill where even-grained granite invades porphyritic granite (39, p. 220), the younger intrusions possess the lower index numbers. At Mt. Korong where older and younger granites are recorded (74, p. 9), the index number for the older porphyritic type is 4·70; that for the younger, fine-grained intrusion is not available, but would probably be lower since it is described as having only a very small amount of biotite (74, p. 33).

Summary and Conclusions.

The heavy mineral analyses of over one hundred Victorian granitic rocks show that granodiorites have greater index numbers than most granites due principally to increased development of ferromagnesian minerals in the granodiorites. Some of the granites contain larger proportions of heavy minerals than others, due to varied amounts of assimilation or of gas fluxing, resulting in increased index numbers which in some instances range up to the average index numbers for granodiorites. In like manner, granodiorites range towards the index number province of the diorites.

Evidence from the study of rock sections, chemical analyses, etc., of the granitic rocks subjected to heavy mineral analysis, indicates that rocks having index numbers below 7 can be grouped with the granites (an exception being that of the Maldon granodiorite), and those having index numbers above 10·5 (except where shown to be contaminated granites or to have been subjected to considerable gas fluxing) with the granodiorites. Seventeen examples with index numbers between 7 and 10·5, however, could not be specifically classed with either the granites or the granodiorites on heavy mineral analysis alone. The evidence supplied by their index numbers had to be supplemented by detailed thin section investigations and Rosiwal micrometric analyses. The results of the heavy mineral work in conjunction with other criteria, indicate that one of the granitic rocks (i.e. that from Trawool), previously referred to as adamellite, is better described as a contaminated granite, and the remainder as granodiorites. Thirty-three heavy mineral species are recorded, and the form and habit of some of them indicated.

The examination of the results of the heavy mineral analyses indicates that many of the Victorian granitic rocks have been contaminated by the assimilation of foreign material, some to greater extent than others, but little evidence of the part played by differentiation can be brought forward. Many of the magmas appear to have been relatively lean in mineralizers, because among the pneumatolytic minerals characteristic of wet magmas (beryl, tourmaline, monazite, fluorite, and cassiterite), beryl and monazite do not appear in the heavy mineral assemblages, and the others are relatively scarce, not being nearly so widely distributed and abundant as in certain of the English (31), Irish (62), and Scottish (46) granites. For this reason, most of the Victorian magmas would appear to have been dry magmas (63, p. 589), but it remains possible that many of the outcrops may represent low levels of erosion in the intrusive masses, where evidence of the existence of pneumatolytic minerals has been removed as a result of long continued de-roofing.

The correlation of or differentiation between the various granitic rocks in Victoria by means of heavy mineral index numbers and assemblages is found to be generally of greater value in small masses and over short distances in many of the larger masses than between masses that are widely separated. In many examples, differences in the heavy minerals reflect differences in the intrusive histories, but in others variations in the primary accessory minerals point to different magmatic origins. Differences between widely separated masses are greater than similarities, but small outcrops close to one another in the field, or near to larger outcrops, are frequently found to be co-magmatic with the neighbouring masses, according to the heavy mineral analyses. In the comparisons of the heavy mineral index numbers and assemblages for rock specimens from different localities in one and the same granitic mass, the heavy mineral analyses clearly show that some of the larger exposures are strikingly uniform in character, and the present surfaces might represent levels in the intrusions where contamination products have been so digested as to form a magma whose component parts were in equilibrium. In other instances, sets of heavy mineral analyses from one and the same outcrop show considerable variations, indicating probable closer proximity to the roofs of the intrusions and variable amounts of assimilation.

Acknowledgments.

The author is grateful to Professor E. W. Skeats and to Professor H. S. Summers for permission and laboratory facilities to carry out this investigation of the heavy mineral content in some of the Victorian granitic rocks; to Dr. E. S. Hills, who collected many of the specimens from the north-western and western outcrops in the State and supplied information concerning their occurrence; and to Dr. F. L. Stillwell and Dr. A. B. Edwards for advice during the preparation of the manuscript.

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